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Bioelectromagnetic Effects of the Electromagnetic Pulse (EMP)

by
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Abstract

The public has expressed concern about the biological effects and hazards of non-ionizing electromagnetic fields produced by the electromagnetic pulse (EMP) simulators that simulate the EMP emanating from a high-altitude nuclear explosion. This paper provides a summary of the bioelectromagnetic effects literature up through the present, describes current occupational standards for workers exposed to the EMP environment, and discusses the use of medical surveillance as it relates to the potential human health hazards associated with exposure to the EMP environment.

Keywords: medical surveillance, Thermal studies, laboratory studies, epidemiological studies, (KR)

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1. Purpose

The purpose of this technical letter is to summarize the literature on bioelectromagnetic effects, including the results of animal studies, laboratory studies, and epidemiological studies, as well as medical surveillance of workers exposed to electromagnetic fields. We relate this literature to the potential human health hazards of the electromagnetic field environment as generated by electromagnetic pulse (EMP) simulators.

2. Introduction

Recently, the public has expressed concern about the biological effects of non-ionizing electromagnetic fields. Moreover, a specific concern has been voiced over the hazards associated with the environment produced by simulators designed to produce electromagnetic fields that are similar to the EMP emanating from a high-altitude nuclear explosion. Early studies [1–3] attempting to define safe levels of EMP simulator environment exposure for EMP workers concentrated on biological effects in animals. Other studies have examined the bioelectromagnetic effects of radio frequency (rf) radiation [4]. Taylor [5] has summarized studies of bioelectromagnetic effects of EMP published between 1967 and 1987. EMP and radio frequency (rf) radiation are compared in sections 3 and 4 of this technical letter.

Quite often, effects which may be due to EMP are confused with hazards caused by rf radiation. Cahill and Elder [6] have edited a critical review of available literature on biological effects of rf radiation for the Environmental Protection Agency. The purpose of the review was to summarize and evaluate the existing database up to 1982 for use in developing rf radiation exposure guidance for the general public. In 1977, Bruner [7] published the results of a similar review addressing the results of studies investigating the occupational safety and health aspects of EMP exposure. This technical letter reviews the existing EMP biological effects literature up to 1987 and supplements the Taylor report with the results of more recent studies.

The nuclear EMP and EMP simulator environments are reviewed briefly in sections 3 and 4; a review of existing exposure standards for workers is given in section 5; a description of exposure conditions, explaining the difference between single-pulse, repetitive and continuous wave exposures, is given in section 6; the results of medical surveillance programs are discussed in section 7; the findings of

animal studies performed over the past 25 years are reviewed in section 8; finally, conclusions based upon this review of existing literature on biological effects of EMP exposure of humans and recommendations are given in sections 9 and 10.

3. EMP Electromagnetic Environment

The EMP produced by a nuclear detonation at high altitude has been the subject of a great deal of theoretical and experimental research, as well as considerable controversy, for nearly 28 years. Long known within the defense community, EMP has come to public attention in recent years as the subject of popular and semitechnical writing. Nelson DeMille's novel, *The Talbot Odyssey*, for example, deals with an impending Soviet EMP attack on the United States that is intended to paralyze the country by disrupting its power networks and transportation systems. Numerous magazine and newspaper articles on EMP—some accurate, others merely sensational—have also appeared in recent years.

Before we discuss the possible biological and health effects of EMP, it is important to clarify the phenomenon itself as well as electromagnetic effects generally.

Electromagnetic waves of all frequencies carry energy. According to quantum mechanics, such waves can also be thought of as packets of energy called photons. The energy of a photon is given by

$$\text{energy} = hf\,,$$

where

$h = 6.63 \times 10^{-34}$ joule seconds (Planck's constant) and
f = frequency.

The energy of a photon is thus directly proportional to the frequency of the radiation. When the frequency approaches or exceeds 3×10^{15} Hz (the ultraviolet range), the photon energies equal or exceed 2×10^{-18} J, or 12.4 eV, and become comparable to the binding energy of electrons to atoms. This high-frequency radiation (x-rays, gamma rays, etc) is referred to as *ionizing radiation*; that is, radiation that will remove electrons from atoms, creating ions. Since even the weakest chemical bonds have energies that are several orders of magnitude greater than those of photons in the rf or microwave range (10^{-3} eV or less), rf waves are referred to as *non-ionizing radiation.*

Most forms of rf waves occur at or near single frequencies. Moreover, radio waves are mostly used in the continuous wave mode (that is, once the source begins to radiate at a single frequency, it continues to radiate at that frequency until it is turned off), in the periodic (repetitively) pulsed continuous wave mode, and in the AM and FM modulation mode.

The immense amount of energy liberated by a nuclear explosion, principally in the form of x-rays, gamma rays, and high-energy neutrons, produces a wide range of effects. The well-known effects of a near-surface or ground burst—including blast, ground shock, and thermal radiation—are actually indirect, resulting from conversion of the bomb's energy into thermal and kinetic forms. On the other hand, energy effects on satellites and missiles in flight caused by a detonation in space are direct. In these cases, the energy from the detonation interacts directly with the target system to induce malfunction or damage. The detonation also changes the surrounding environment, producing propagation disturbances affecting communications ranging from radio to optical frequencies. High-altitude EMP results from the conversion in the earth's ionosphere of weapon gamma-ray energy to rf electromagnetic energy, which propagates toward the earth's surface.

Because electromagnetic effects are less familiar than blast and thermal effects, it is useful to remind ourselves that we spend our lives surrounded by electromagnetic fields, including the radio waves emitted by radio and television stations and the static electric and magnetic fields of the earth itself. These fields are all benign in that they cause no apparent harm to people or to exposed electronic equipment. Stronger electromagnetic fields may be harmful in some cases. A radar signal, for example, is harmless to the systems that it interacts with, if the interaction occurs at the distances associated with normal operation. A similar field, generated in a microwave oven, can cook food. It could also cause great damage to unprotected systems—a portable radio or the family cat—if these are exposed to it. Lightning, a common natural electromagnetic phenomenon, can cause obvious damage to systems that it strikes. It can also interfere with the operation of electronic circuits within its electromagnetic field, even if the circuits are not struck directly.

Similarly, EMP is a potential source of electromagnetic disruption. It can cause malfunction of or damage to unprotected electronic circuits and components. Critical defense systems need protection from EMP.

Ways of mitigating EMP effects have been developed, which are being integrated into the designs of many new electronic systems.

4. EMP Simulators

The primary evidence for the susceptibility of modern electronics systems to EMP has been obtained from tests wherein representative systems have been exposed to simulated EMP environments or EMP-induced stresses. This kind of testing is typically performed using EMP environment simulators, where an EMP-like electromagnetic field is generated with conventional pulse-power sources and is used to illuminate the test object.

EMP simulators come in two general types, depending on the method used to simulate the EMP environment: radiating and bounded-wave simulators. Both types of simulators produce an EMP which travels through the air to impinge on an intended test object. The two types differ in that the radiating simulators produce EMP in the open, and the bounded-wave simulators produce EMP in an enclosed space.

The operation of an EMP radiating simulator is very simple. A large amount of electrical energy, stored on charged capacitors, is discharged through a switching circuit into an antenna. A huge surge of electrical current flows on the antenna, producing an EMP that radiates outward from the antenna. This EMP decreases in intensity as it spreads outward into the surrounding space. A test object is located at a distance from the antenna that corresponds to the desired intensity for the test.

An EMP bounded-wave simulator discharges the stored charge through a network of electrical conductors that are designed to direct the EMP into an enclosed volume, not into the surrounding space. The test object is placed on a test pad in the interior volume of the EMP bounded-wave simulator. Compared to EMP radiating simulators, higher energy levels can be achieved for testing, since less energy is directed out into the surrounding space.

An example of a bounded-wave simulator is the Trestle facility at Kirtland AFB near Albuquerque, NM. This simulator was designed to simulate the EMP environment experienced by an aircraft in flight and can accommodate aircraft as large as a B-52 or 747. Other simulators have been built that are suitable for simulating the EMP environment to which ground- or ocean-based systems would be exposed.

Examples of free-field EMP simulators are those at the Harry Diamond Laboratories' Woodbridge Research Facility (WRF). The electromagnetic fields produced by the WRF EMP simulators do not generate ionizing, ultraviolet, visible-light, or infrared frequencies. They produce fields only in the rf region of the electromagnetic spectrum up to ~100 MHz (1×10^8 Hz).

The electromagnetic wave produced by EMP simulators is a transient. That is, the simulator source radiates a single pulse of energy that lasts for a finite and very short period of time (~1 μs). It does not radiate another pulse until the generator storage capacitor devices are recharged. The pulse is characterized by a very rapid rise (~10 ns or 10×10^{-9} s—10 billionths of a second) to a peak of up to 50 kV/m and then decays to near zero in 1 μs (1×10^{-6} s—a millionth of a second). EMP simulators typically produce a pulse once every several minutes.

5. Current Standards

Based upon research performed in the late 1960's through mid-1970's, the Air Force, Army and DoD have published EMP exposure levels as protection standards for EMP simulator workers. In 1981, the Department of the Army issued Army Regulation 40-583, which established the maximum field strength limit for single-pulse human exposure at 100 kV/m, irrespective of the EMP frequency content of the pulse. In 1986, the Department of Defense issued DoD Instruction 6055.11, which set the maximum field strength limit for single-pulse exposure at 100 kV/m, likewise irrespective of the EMP frequency content. The supporting documentation for this limit is Air Force Occupational Safety and Health standard 161-9, dated October 1978.

The American Conference of Governmental Industrial Hygienists (ACGIH) [8] also set a 100 kV/m exposure threshold limit value in 1983. Some industrial standards have been set below this value. In the early 1980's, Boeing used an occupational EMP exposure standard of 5 kV/m. In the late 1970's, this limitation was altered to include 50 kV/m as the maximum exposure limit on a permission basis. In 1983, Boeing published its Occupational Safety and Health Standard and identified 50 kV/m as its maximum permissible limit. For a time, Bell Laboratories [9] maintained its EMP exposure standards for workers in the 1- to 5-kV/m range. However, it has recently modified its standard to a maximum limit of 100 kV/m.*

**Private communication to J. S. Dancz (SAIC) from R. C. Petersen (AT&T Bell Laboratories), 22 January 1988: "We no longer recommend an upper limit of 5 kV/m. The value we now recommend is ACGIH limit of 100 kV/m for those personnel directly involved with EMP testing."*

6. Exposure Conditions

Most electromagnetic bio-experiments have used continuous wave (cw) or very rapid periodic pulsed cw sources, rather than a single transient pulse source like an EMP simulator. There are crucial differences between these types of non-ionizing radiation and the EMP type, whether we consider thermal or nonthermal effects.

As indicated in the literature, thermal bioeffects can occur in response to electromagnetic radiation under certain conditions, specifically for high-level cw radiation and for cw radiation that is pulsed at high repetition rates (many pulses per second). Generally, EMP radiating simulators produce pulses of very short duration and with low repetition rates (typically one pulse every 5 minutes). The short duration and low repetition rate of EMP pulses suggest that thermal effects will not result from EMP simulator operations.

The existence of nonthermal effects has also been reported in the literature. Experiments have shown the effect of electromagnetic fields on biosystems to depend on the frequency and amplitude of the source, as well as the modulation and pulse repetition frequency of cw sources. For pulsed electromagnetic fields, results have been seen to depend on the pulse amplitude, duration, and fall time.

Because of this varied dependence on the specific parameters of the electromagnetic field source, care must be taken in relating bioeffects research using other electromagnetic waveforms to possible EMP effects; the physical interactions involved have distinct differences. Specifically, it would be unwise to generalize the results of studies of the effects of cw (or high-repetition-rate pulsed cw) non-ionizing radiation to EMP effects, for the following reasons, among others:

- A typical EMP simulator is actually operating only about 2×10^{-7} percent of the time, in contrast to emitters of cw non-ionizing radiation; these are operated either in a fully continuous mode or in an intermittent mode. Radars, for example, are usually in operation about 0.1 to 10 percent of the time.
- A typical EMP simulator produces most of its energy in the frequency range from 10^5 to 10^8 Hz, in contrast to emitters of cw non-ionizing radiation; these may have energy in the frequency range from as low as 10 to 100 Hz and as high as 10^{12} to 10^{14} Hz, usually with a much smaller frequency spread or bandwidth than EMP.

- EMP simulators produce low average powers but high peak power (because they radiate at high strength for an extremely short time), in contrast to cw emitters, which produce high average powers but low peak power (because they radiate at low strength over a long time).

Although in certain respects the biological effects of EMP may be comparable to those of cw non-ionizing radiation, the following must be recognized:

- Much less laboratory effort has been devoted to investigating the biological effects of EMP compared with those of cw non-ionizing radiation.
- Much less occupational exposure data are available for EMP biological effects versus those for cw non-ionizing radiation, because vastly fewer people encounter the EMP form of non-ionizing radiation in their workplaces.
- The problems in measuring the actual exposure parameters of EMP pulses (which have durations as brief as 800 ns) are much greater than for cw non-ionizing radiation.
- There is much greater uncertainty about the intrinsic ability of biological systems to respond rapidly enough to be affected by the extremely brief pulses that characterize EMP.
- The effects of EMP appear more difficult to determine experimentally than those of cw non-ionizing radiation. The usual technique would be either to increase power levels until biological effects are observable and then extrapolate the actual data back to the desired lower exposure levels, or to extrapolate the actual data to higher levels to simulate greater exposure. However, as pointed out above, the EMP energy is already being delivered at a much higher peak power level than that of cw non-ionizing radiation, but since the EMP energy is in the form of a very short pulse there is a much shorter exposure. Thus, an EMP simulator produces a much lower average energy exposure over a given time than does a typical high-power emitter such as a radar.

Because of such considerations, it is preferable to examine research using EMP-type waveforms rather than that using cw and pulsed-cw electromagnetic waveforms; although results of EMP studies are less plentiful, they are available [5–16] and are discussed in the following section.

7. Human Medical Surveillance Studies

During the operation of EMP simulators, site personnel work regularly in the electromagnetic fields that these simulators produce. Possible injurious effects and safe exposure limits have been of concern since these simulators began operation in the 1960's.

No experimental studies have been conducted with humans; however, from the mid 1960's through 1976, some 600 USAF, USN, Boeing Co., EG&G Inc. and Bell Labs employees associated with the operation of EMP simulators (exposed to field strengths of less than 100 kV/m) have been under medical surveillance through medical exams and monitoring. The following conclusion was reached [7]:

> "Experience with EMP worker exposures has accumulated now for more than 20 pulser projects, some of which have been in operation over 10 years. To date, no adverse health effects of such exposure have been determined from either the repeated physical examinations performed or the personal observations of the nearly 600 individuals covered in this review. Furthermore, no reports of exposed employees of reliable motivational-emotional changes (e.g. psychasthenic syndrome) have been ascribable to the EMP exposure environment per se ... Thus, sufficient no-effect findings ... seem now to exist to confidently allay fears of an EMP worker exposure hazard, at least for within a 10 year observational time frame."

Because of the lack of any apparent effects, the selective medical surveillance for military workers exposed to EMP was discontinued by the USAF in 1975.

The U.S. Navy reported its experience with the exposure of its personnel to EMP simulator environments [10]:

> "As amplification of the above mentioned industrial hygiene data on EMP workers, the Navy has a limited data base of its own. The Navy has operated the previously mentioned EMPRESS I simulator at Pt. Patience, MD, since 1972. The Navy has also operated several EMP simulators at the nearby Naval Air Test Center (NATC), Patuxent River, MD, for various periods since the early-to-mid-seventies. These Navy facilities have all been operated by civilian Navy personnel of the Naval Surface Weapons Center (NSWC). Approximately 50 personnel have been involved in these tests on a very intermittent basis for

periods up to 10 years. Also, some of these personnel have been involved in extensive testing conducted with the various EMP simulators located at Kirtland AFB, NM. Besides the testing involving the NSWC personnel assigned to the group responsible for this type of work, there have also been a large number of other NSWC personnel, as well as non-NSWC personnel, who have participated in five short-time (7–10 days) EMP ship's tests conducted at EMPRESS I. The results of all of these human exposures have been no observable medical problems correlatable with the EMP exposures. Medical examinations on the Navy civilian personnel most closely involved in the EMP simulator work have been conducted by Navy doctors, and the results, reviewed. They have not shown any correlatable changes."

In 1988, Aldrich reported that the Boeing Corporation had the only ongoing medical surveillance program for EMP-exposed workers in the United States. Aldrich reports [11] :

> "The Boeing system identifies all workers exposed to greater than 1 kV/m (below 1 kV/m is considered non-occupational exposure). Workers exposed to between 1 and 5 kV/m are followed for identification of subsequent health problems and to ascertain cause of death. Only those workers who are exposed to greater than 5 kV/m are required to have routine medical examinations, in an effort to detect short-term health effects. All occupational exposures of 10–50 kV/m are monitored and logged; Boeing's corporate permissible exposure limit is 50 kV/m. With over 15 years of worker follow up, including annual physical examinations, no adverse effects have been observed or reported among over 200 workers exposed to thousands of pulses. There have been three cancers among the exposed workers, but this number does not indicate an excess occurrence over the age, race and sex adjusted expected rates for the group, over the time period studied ... Due to no findings of any evidence of significant health effects among Boeing employees ... Boeing currently is considering the value of continuing its EMP surveillance program."

In 1987, the Boeing Corporation [8] concluded that

> "Annual physical examinations cannot be effectively used to monitor reproductive status and/or evaluate the long term effects of overexposure, detect early disease, evaluate the effec-

tiveness of controls or make any further contribution to the risk assessment of EMP exposure ... [and that] Future medical surveillance should consist of epidemiologic studies of morbidity and mortality patterns over a substantial time."

However, the U.S. Navy reported that it would institute an EMP human health monitoring program for personnel working in support of test activities associated with the Navy's EMPRESS II EMP simulator [12]. This program [13] establishes procedures to be followed for exposure or suspected exposure to fields in excess of 100 kV/m. Additionally, it observed that medical screening and surveillance of military personnel are required in accordance with OPNAVINST 5100.23B, *Navy Occupational Safety and Health (NAVOSH) Program* of August 1983; civil service personnel medical screening and surveillance programs and procedures are established and implemented at the discretion of the parent facility's Commanding Officer; and any contractor personnel whose work assignment is on board the EMPRESS II facility during pulsing operations or on the associated test ship are required to have a preplacement medical examination. Contractor personnel will also be required to have a medical examination at the end of employment. This exam will include a full ocular surveillance in accordance with OPNAVINST 5100.23B. A preplacement examination will serve as a baseline for the individual.

8. Animal Studies [9]

A series of experimental animal studies was performed during the 1970's by scientists at the Armed Forces Radiobiology Research Institute [14–17] to determine if radiation from EMP simulators induced measurable non-behavioral responses. Beginning at 4 months of age, 300 male laboratory rats were continuously exposed to EMP radiation (5 pulses/second; 447 kV/m peak field strength) for the balance of their normal life expectancy (94 weeks). A similar group of nonexposed rats served as controls. This resulted in exposure to a total of 2.5×10^8 pulses. Over that period, blood chemistry, blood and bone marrow cellular concentration, chromosomal aberrations, and erythrocyte production were examined, with interim results reported in Skidmore and Baum [15] and Baum et al [14] after the test rats had been exposed for 38 weeks to a total of 10^8 pulses.

No EMP-related injurious effects were noted in any of the studies. The interim results noted an increase in blood reticulocytes and a decrease in platelets in the exposed group compared with unexposed controls. However, both parameters remained within normal limits and the dif-

ference became undetectable in the later portion of the study. Bone marrow analyses revealed no changes in the exposed animals versus controls, and there were no detectable differences in chromosomal aberrations. Histological examinations revealed no differences between exposed and nonexposed animals. Twenty 4-month-old female rats similarly exposed showed no detectable difference in the development of mammary tumors compared to a group of 20 nonexposed controls after 38 and 94 weeks. Exposure to as many as 2.5×10^8 pulses had no effect on the fertility of male rats versus controls. Exposed male and female rats which were mated yielded litters which were similar in number to those borne by the control group. No anatomical abnormalities were found in the progeny which were exposed throughout gestation.

A group of 42 mice of the AKR/J leukemia-prone strain were subjected to 8.6×10^7 pulses [14,15]. Compared to a group of 25 controls, EMP exposure did not induce the early onset of spontaneous AK leukemia in the test mice. About 45 percent of controls contracted leukemia versus about 20 percent of the exposed group. It was concluded [16] that based upon tests of rodents over 94 weeks of exposure (subjected to many times the number of pulses to which an EMP facility worker would be exposed) no biological measurements indicated any effects from EMP exposure.

Later experiments [17] with dogs reinforced these conclusions. Using 26 one- to two-year-old male and female beagles in test and control groups, similar analyses were made of blood and bone marrow. Test animals exposed to 5.8×10^6 pulses over 45 days (5 pulses/second; 447 kV/m peak field strength; 8 hours exposure/day) showed no differences in blood and bone marrow analyses when compared to the controls. No effects on fertility were noted when exposed males and females were mated. The pregnant females were exposed between days 10 and 55 of the gestation period and had litters of completely normal pups, with no variation in litter size from a similar nonexposed control group.

Diachenko [18] performed experiments on the effect of EMP modulated at 2450 MHz on the operant behavior of rats. (Such modulation concentrates the EMP energy near a frequency of 2450 MHz.) He subjected the rats to EMP at 125 kV/m at a rate of 4 to 10 pulses per second for one hour per day, followed by performance testing each day for five days. No effects on operant behavior could be detected between performance before exposure (control) and after exposure to the EMP.

The onset of bioeffects due to the thermalization of energy deposited by fields is generally accepted by the scientific community. Another means whereby external electromagnetic fields can couple to biological systems is via putative nonthermal phenomena; most studies suggesting their occurrence are highly controversial. To complicate the matter, an inability to replicate given experiments in independent laboratories has added to the skepticism. Nevertheless, there is mounting evidence that such effects are real. A recent examination [19] by a National Academy of Sciences review panel on *Nonthermal Effects of Nonionizing Radiation* recommended that a more concerted and focused effort be implemented to replicate key experiments that suggest nonthermal bioeffects. The intent is to elucidate the basic physical mechanisms underlying the cause of such effects.

A recent biostatistical review [4] of 32 studies of the biological effects of rf electromagnetic (RFEM) energy led the authors to conclude that no decisive evidence was presented for deleterious effects of RFEM radiation at low levels of exposure. Further, they concluded that except for laboratory studies where RFEM radiation produced substantial heating, no conclusive evidence of harmful effects was found.

No cases of nonthermal responses in humans have been scientifically documented—however, one could conclude that nonthermal effects might be masked by thermal effects [20].

In general, nonthermal biological responses to very-low-intensity electromagnetic fields, while apparently highly frequency specific, have been reported at frequencies ranging from 16 Hz to several hundred gigahertz. The results strongly depended on the particular biosystem.

Examples of such effects include alterations in the efflux of divalent calcium ions from embryonic chick forebrain tissue [21], variation in the growth rate of aqueous yeast cultures [22], reduction of puff size in the puffing of giant chromosomes [23], and changes in the permeability of the cell wall of human, dog, and rabbit erythrocytes exposed to repeated EMP pulses at 480 kV/m [24]. All reported observations of nonthermal effects have been from *in vitro* studies (i.e., "test tube" studies). Cleary [24] conducted *in vivo* experiments with Dutch rabbits exposed to repeated pulses of EMP at 150 kV/m for 2 hours, and could detect no statistically significant changes in serum chemistry; this is in contrast to his *in vitro* studies of erythrocytes [24].

9. Conclusions

There are different scientific approaches for measuring the bioelectromagnetic effects of EMP. The results of *in vitro* studies, animal studies, and medical surveillance studies have been reviewed in this technical letter: instead of such studies, it would have been preferable to have had the results of human epidemiological studies. However, each approach has its strengths and weaknesses when the following factors are considered: control over experimental conditions, statistical power, and relevance to humans. In *in vitro* studies, there is perfect control over experimental conditions and high statistical power; however, the results are only remotely relevant to humans. In animal studies, usually the control over the experimental conditions is good to very good, the statistical power is moderate, and the relevance of the results to humans is fair to good. Finally, in human epidemiological studies, there is poor control over experimental conditions and limited statistical power, but the results have good relevance to humans. These study strengths and weakness should be borne in mind as the reader reviews the conclusions below.

Additionally, the EMP bioelectromagnetic effects literature reviewed in this technical letter is a small fraction of the existing literature on the bioelectromagnetic effects of non-ionizing radiation. This technical letter does not attempt to assess the relevance of the non-EMP literature to the EMP human health problem reviewed here.

The occupational exposure guideline for EMP is 100 kV/m. This is far higher than usual exposures with EMP simulators. Evidence from all the biological data which have been collected to assess the potential EMP health hazards to humans does not establish that the EMP-type electromagnetic environment represents either an occupational or a public health hazard. Laboratory research and multiple years of observations on workers in existing EMP simulation facilities suggest that there are no acute or short-term health effects. The question of very long-term effects must still be addressed.

The U.S. Air Force discontinued its medical surveillance program in 1975. Boeing, which has had a medical surveillance program in place since the early 1970's, is considering discontinuing it. The U.S. Navy has instituted a Human Health Monitoring Program for personnel working in support of test activities associated with their EMPRESS II EMP simulator. This program establishes guidance for baseline data and procedures to be followed for exposure or suspected exposure to fields in excess of 100 kV/m.

Even with all this negative results data, there is persistent public apprehension about general health risks posed by electromagnetic fields [25], particularly the electromagnetic fields associated with the 60-Hz power distribution system. Additionally, there is presently a case in the Washington State court system in which plaintiff Robert Strom is suing the Boeing Corporation, claiming that his exposure to EMP fields as a result of his employment is responsible for his contracting chronic myelogenous leukemia. This case is an example of the widespread public mistrust of scientific claims of safety based on the lack of hard evidence of harm.

10. Recommendations

We lack not only decisive evidence for deleterious effects of RFEM radiation at low levels of exposure (where there is no risk of substantial heating), but also models of basic physical mechanisms that might cause such effects. Against such a background, the technical community cannot argue on any well-founded scientific basis that a medical surveillance program should be established at this time. However, the public's perception is that the risks associated with electric and magnetic fields have not yet been established. Figure 1 shows the results of a study of the perceptions of 175 college students of the risks associated with 81 hazards [26]. The respondents' ratings of the hazards according to 18 different characteristics revealed that certain subsets of these characteristics were correlated, falling into two broad groups; the researchers summarized one cluster of characteristics ranging along the scale of "known" to "unknown risk" and the other as along the scale of "no dread" to "dread risk" (see the diagram at the bottom of the figure). As shown in the upper part of the figure, "electricity radiation" (electric fields) is high on the "unknown risk" scale and just over the center axis on the "dread risk" scale.

In the light of such public perceptions, it is important to take precautions to ensure that employees are not subjected to unnecessary real or perceived risks in the work place. To ensure that the work place is safe and to reduce the perception of risk, the following actions are recommended:

- Urge U.S. Army EMP employees to participate voluntarily in a medical surveillance program. The biological parameters to be monitored in such a program would be determined by the U.S. Army Surgeon General to investigate specific health consequences of EMP exposure.

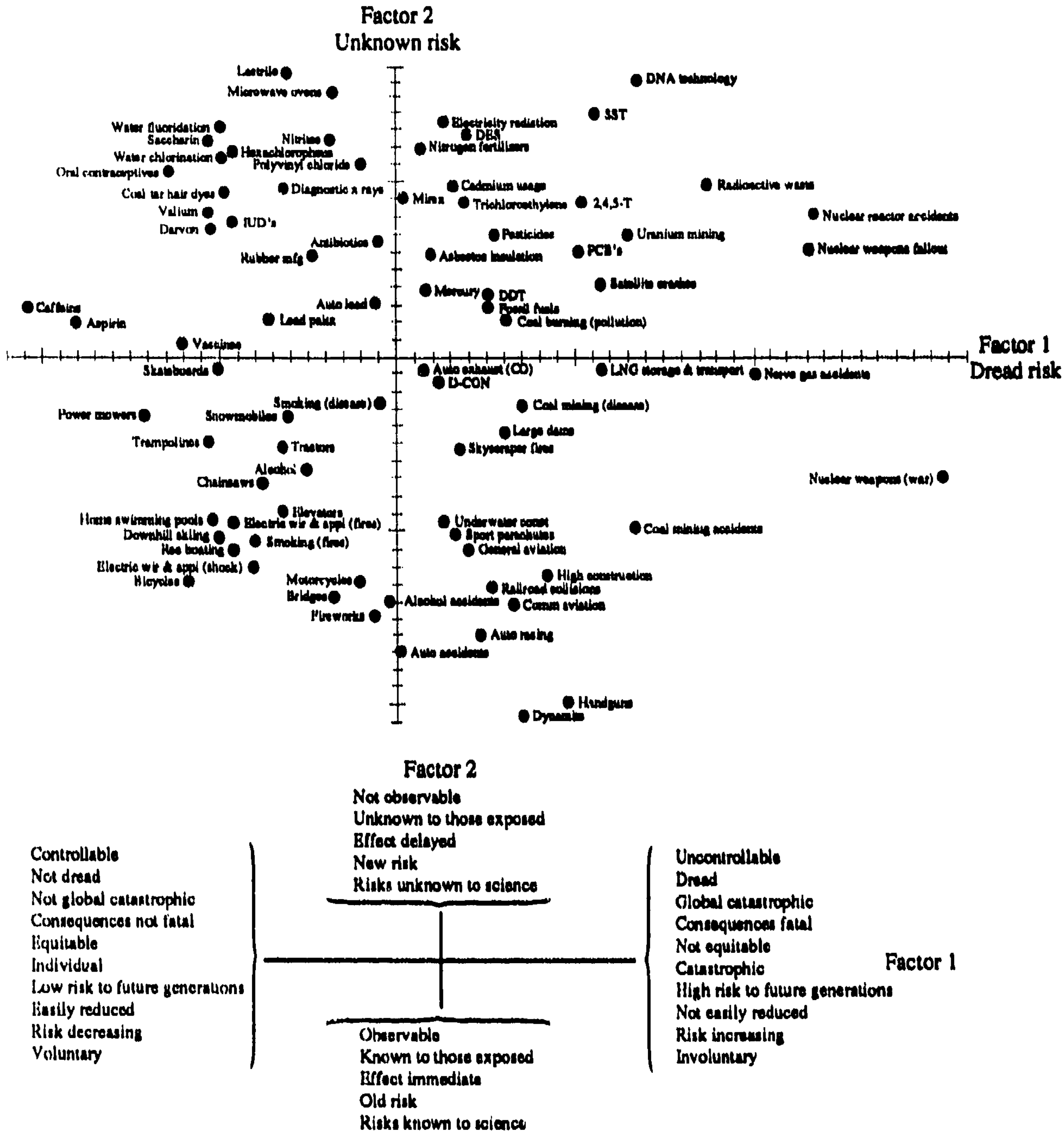

Figure 1. Location of 81 hazards on "unknown risk" and "dread risk" scales; these two factors were derived from the relationships among 18 risk characteristics. The characteristics making up each factor are indicated by the lower diagram. Notice the location of "electricity radiation" (electric fields). (Adapted from P. Slovic, S. Lichtenstein, and B. Fischoff, "Characterizing Perceived Risk," in *Perilous Progress: Managing the Hazards of Technology*, R. W. Kates, C. Hohenemser, J. X. Kasperson, editors, Westview, Boulder, CO (1985), pp 91–125.)

- Continue to use the "as low as reasonably achievable" (ALARA) principle for limiting the exposure of EMP employees to electromagnetic fields in the work place. Moreover, emphasize that the intensity of the electromagnetic field to which the EMP employee is exposed should be kept as low as possible without jeopardizing the accomplishment of the mission.

  Finally, we recommend that the U.S. Army Surgeon General consider the feasibility of designing an occupational exposure surveillance program for U.S. Army EMP workers, one which builds on the existing experience of human exposure to the EMP electromagnetic fields identified in this technical letter. The results could be used in a well-designed epidemiological study with the goal of isolating and identifying those factors associated with the EMP that are hazards to humans. A program of this scope would require the cooperation and approval of the U.S. Army Environmental Hygiene Agency and the U.S. Army Surgeon General.

  Perhaps this proposed program should be modeled on the Navy's surveillance program developed for their EMPRESS II EMP simulator operations. During the program's early phase, the Air Force and Navy could participate to increase the size of the database, assist in the review of data collected, determine the efficiency of the program at predetermined milestones, and participate in the decision to continue the data-collection effort.

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